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Research of CO_2Storage Possibilities to the Underground

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Abstract

Recently, one of the most discussed world-wide problems is Global warming situation. Global warming is probably caused by increased concentration of greenhouse gases at the atmosphere, not only as a result of human activity. Nevertheless, human activity has huge impact on increasing amount of CO_2 at the atmosphere. The international organizations are concerned for this reason. Thus, the possibilities for CO_2 reduction are searched world-wide. One of the possibilities can be CO_2 storage to the suitable geological layers at the underground.

This paper deals with issue of CO_2 storage to the underground. CFD software Fluent will be used for verification of proposed possibilities and result.

1. INTRODUCTION

Many international scientist and experts deal with problem issue of global warming. Their studies show that one of the causes of the global warming could be still increasing carbon dioxide concentration in the atmosphere.

One of the possibilities how to prevent increasing concentration of carbon dioxide in the atmosphere is CO_2 storage to the underground. The project of storing CO_2 to the underground was discovered and it is experimentally verified from the range of ways of carbon dioxide storage to the deeper layers of the Earth crust. Nevertheless, it was proved that this promising method has still many problems which have to be solved.

The paper assesses the current state of knowledge and results which were obtained in the field of carbon dioxide storage to the underground. There is an effort to introduce and ideological intent of CO_2 storageat the area of Czech Republic based on this conclusions. It is possible to elaborate this idea and bring specific practical results in the near future.

The aim of this paper is to compile the possibilities of CO_2 storage to the underground of closed deep mines and then verifying these possibilities using CFD software Fluent.

2. GREENHOUSE EFFECT AND CO_2

The greenhouse effect is a natural phenomenon which occurs since Earth inception, practically, and thus it is a prerequisite for life on Earth. The average temperature at the Earth´s surface will be around -18 °C without occurrence of greenhouse effect. [1], [2].

Some gases in the atmosphere have the ability to absorb infrared radiation from Earth's surface.This natural phenomenon which is called the greenhouse effect, helps to maintain suitable temperatures for life. The main part of atmosphere (99%) is composed by two gases, nitrogen and oxygen, and these gases don´t absorb even emit radiation. Water vapor, carbon dioxide and some other gases which are contained in the air in much smaller quantities, absorb a part of the thermal radiation leaving the Earth's surface; these gases also act as a partial

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"blanket" to radiation and cause a difference of about 21 °C between the actual and the average surface temperature on Earth that is moving at about 15 ° C and -6 ° C value, which would occur only in an atmosphere containing oxygen and nitrogen. Causing of this "blanket" is called natural greenhouse effect and appropriate gasses are called greenhouse gasses. This effect is called naturel because of their occurrence at the atmosphere have been long time before the people life. We speak about increased greenhouse effect in case when the impact of these gasses in the atmosphere is increased by the human activity, such as deforestation and fossil fuels burning. [3], [4].

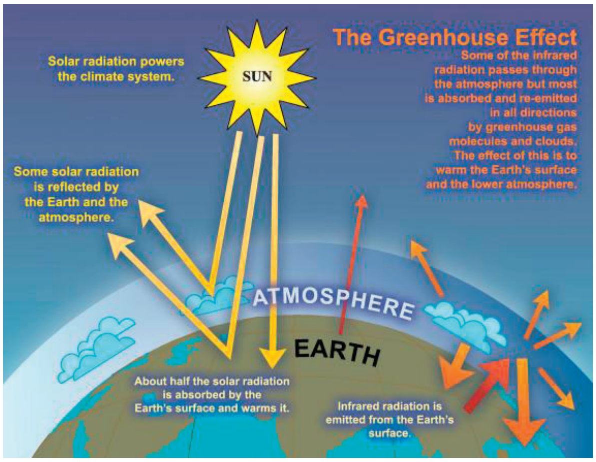

Figure 1. An idealized model of the natural greenhouse effect; source [2]

Many of other gasses participate on greenhouse effect. These gasses arise in connection with human activity especially burning of fossil fuels and thus they have impact to the global warming. We can classify e.g. carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) among these gasses. [4]

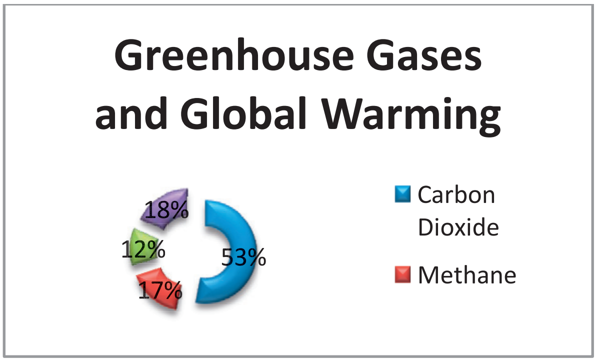

Chart 1. Greenhouse Gases and Global Warming; [4]

Chart 1 shows the relative contribution of each of these gasses to the process of global warming.
Most of carbon dioxide, which is contained at the atmosphere, is natural origin. It originated e.g. from volcanoes eruption, during composting, during biomass burning etc. Carbon dioxide even origin during breathing of people or animal. When we inhale, we suck in air with concentration of CO_2 approximately 0,03 %, but when the air blowing from our lungs it has concentration of CO_2 approximately 4%.
Nevertheless, carbon dioxide is one of the main contributors to the increased greenhouse effect. It contains more than 60 % of increased greenhouse effect, worldwide. CO_2 represents more than 80 % of emissions of greenhouse effect in industrial countries. [8]

3. POSSIBILITIES OF CO_2 STORAGE

Principle of technology of capture and storage CO2 (CCS – Carbon Capture and Storage) is not a difficult, basically. Special separation unit which is located near power plant or industrial building captures carbon dioxide in combustions. Captured gas is diverted by pipeline to the suitable geological area (e.g. extracted oil deposit, natural gas or underground coal deposits), where it is “pumped” into the underground.

Figure 2. Principe of Carbon Capture and Storage; source [12]

4. CO_2 compression, preparation for the transport

Captured carbon dioxide is compressed to the form of dense liquid before the transport. This liquid occupies much less volume than CO_2 in a gas phase. When CO_2 is separated from combustions in power plant or other industrial factory the resulting highly concentrated flow of CO_2 is compressed and cleared of water, which improves the efficiency of transport and storage. Dehydration (water removing) is needed to prevent corrosion of equipment and infrastructure. Compression is done together with dehydration in multi-segment process: repeated cycles of compression, cooling and water removal.Pressure, temperature and water content should be adapted to means of transport and pressure requirements at the place of storing. The key parameters for project of compressors installation are the speed of gas flow, suction and discharge pressure, heat capacity of gas and compressorefficiency. [16]

The basic example of capturing, compression and injection is shown in the Figure 3.

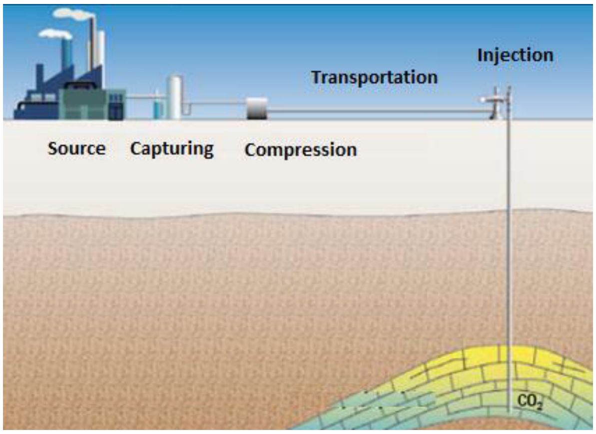

Figure 3. Capturing, Compression, Transportation, Injection; [16]

5. Injection

When CO_2 is transported to the place of storage it is injected to the reservoir, under pressure. The injection pressure must be sufficiently higher than the existing reservoir pressure to reservoirs fluid pushed further from the point of injection.Number of injection wells depends on the amount deposited CO_2, injection rate (the amount of CO_2 injected per hour), permeability and reservoir thickness, maximum safe injection pressure and the type of well. Because the main goal is a long-time CO_2 storage, we have to be sure of hydraulic integrity of the formation. High injection rates can cause increase of pressure in the injection point, particularly in formations with low permeability.The injection pressure should generally not exceed the limit of pressure to create cracks in the rock; otherwise it may cause damage to the overlying reservoir and seal rocks.Geomechanical analysis and modeling are used for determining maximum injection pressure which doesn´t cause the violations of formations.

The above mentioned problems with injection depend on complex processes of interaction substances around the injection well, but also they are strongly dependent on time and distance from the well. The numerical simulations and modeling are used for assessment of these effects.

The injection rate should be handled carefully so as to manage the processes that could reduce the required storage of CO_2. [16]

6. The example of commercial apply of CCS

Despite the fact that Norway produces almost most of its energy in hydroelectric plants and the atmosphere emitting is just 0.2% of global emissions, very intensely concerned with protecting and improving air quality. The first commercial project of capturing and storage of carbon dioxide was in Norway [9]. This is an oil platform Sleipner West [10], [11].

This platform stores about one million tons of carbon dioxide to the geological structures of extracted oil or natural gas deposits under the North Sea surface since 1996. The natural gas, which is extracted under the sea, contains around nine percent of CO_2 that has to be separated.

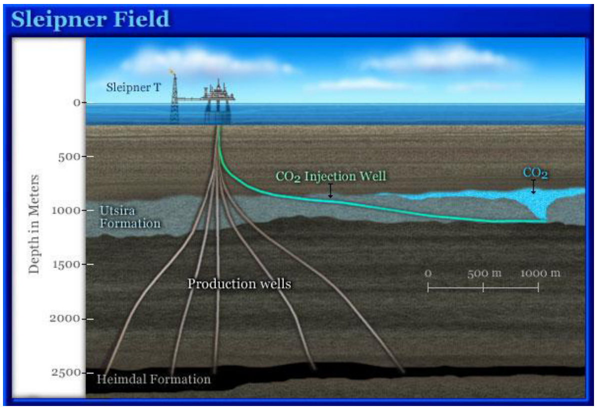

Figure 4. Scheme of Carbon Dioxide Capture and Storage Project at Sleipner field; source [11]

Carbon dioxide thus can be stored in the underground at the same way how the raw materials are deposited for millions years.

7. RECOPOL Project

RECOPOL Project was realized in Poland with EU support that should verify possibility of CO_2 storage in underground deep mine and thus decrease emissions to the atmosphere. Project was begun 1st December 2001 at Silesian Coal District.

The possibility of CO_2 storage was verifying at the mentioned area and also methane obtains at the same time, which should be released during this action. Methane obtained by this way should be used for local energy consumption. [16]

CO_2 was brought in liquid phase (temperature was –200 °C) by trucks and was stored in a two tanks. Then, it was heated and pumped into the coal seam, at a depth of 1050 - 1090 m, several meters below the floor of the deepest mines in Silesia. It was expected that CO_2 will be adsorbed coal which will be emitting its gas, methane, at the same time.

Released methane was drawn by two wells using pump. The injection and production ran from June 2004 to December 2004. It was planned to inject 1 000 tons of carbon dioxide to the deep mine, which is a production almost 10 % of emissions from typical deep mine. [16]

8. CFD SOFTWARE FLUENT

Generally, CFD packages (Computational Fluid Dynamics) are such programs that use computational technology for modeling and simulations of phenomenon of fluid flow. CFD is a computational technology that enables us to study the dynamics of things that flow.

Using CFD packages we can create a computational domain which represents a system or device that we want to study. Then, the basic equations from fluid mechanics, chemistry and other possible reactions etc. are applied to our domain. The outputs of these packages can be numerical data, figures or animations which predict fluid flow behavior and related physical phenomena.

These programs are tools not even for simulation of fluid or gas flow but you can also simulate heat and mass transfer, the interaction between solid and gaseous phases, etc.

Very important part of the model creation at CFD packages is right definitions of boundary conditions. Boundary conditions determine flow and heat values at the boundary of the physical model. Because they are a critical part of numerical simulations, the great importants is put to their correct settings.

9. OUR IDEALISTIC SUGGESTION OF STORAGE

This idea suggestion comes out from RECOPOL Project and it should assess feasibility and risks of CO_2 storage to the deep mine and obtain some volume of methane at the same time. Presented suggestion isa part of the Bachelor thesis [16].

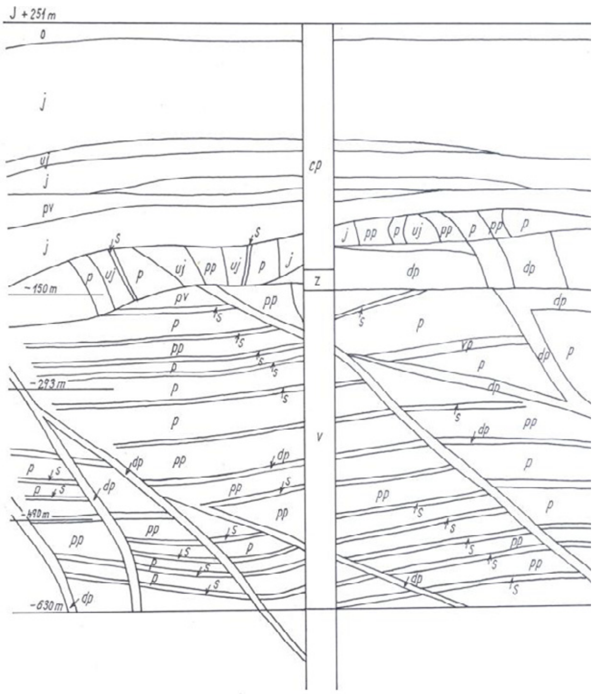

Figure 5. Geological profile of Pascov mine

The area of mine Paskov at south part of Ostrava – Karviná district was chosen like a starting model area. This mine was active at the past and it still products significant amount of methane now.

Geological profile of mine Paskov is shown at the Figure 5. There are several types of rocks: claystone (j), duststone (pp), sandstone (p), coal claystone (uj) etc.

Next table shows geological structure at the modeled area and their permeability values.

Table 1. Geological Structure and permeabillities of rocks

Rock	*Permeability [m^2]*
Claystone	$1 \cdot 10^{-14}$
Coal claystone	$1 \cdot 10^{-12}$
Sandstone	$1 \cdot 10^{-11}$

Duststone	$1 \cdot 10^{-10}$
Duststone with cobbles	$1 \cdot 10^{-13}$
Coalbed	$1 \cdot 10^{-7}$
Topsoil	$1 \cdot 10^{-6}$

We assume a massive pressure 12 MPa at depth 500 meters under surface and 25 MPa at the depth 1000 meters at the deep mines at Ostrava – Karviná district. The temperature can be 30 °C and maybe more at the depth around 1000 meters. Such conditions significantly determine state of aggregation of CO_2, as we can see at Figure 6.

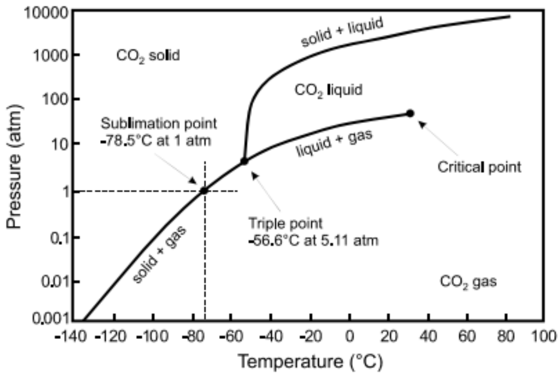

Figure 6. Pressure-Temperature phase diagram for CO_2; source [18]

Our first purpose and first aim was to detect whether the stored CO_2 couldflow toward to surface and affect vegetation.

9.1. Darcy´s law

It can be used calculation according to Darcy law for determining a leaking gas at the first step. Darcy law defines fluid flow through a porous medium.

$$Q = kS \cdot \frac{\phi_a - \phi_b}{L}$$

Q flow rate of fluid or gas[m³/s]
k Darcy´s constant, sometimes called hydraulic conductivity or filtratioin coefficient [m/s]
S surface [m²], the flowing medium flows through this surface
ϕ_a piezometric height at the inlet place of flowing medium to the material
ϕ_b piezometric height at the outlet place of flowing medium from the material
L distance between places*a* and*b*

Darcy´s constant, sometimes called filtration coefficient is possible to obtain from the following equation:

$$k = \frac{v}{I}$$

Piezometric gradient *I*is equal:

$$I = \frac{\Phi_a - \Phi_b}{L}$$

$$I = \frac{24\,898\,675}{1\,000} = 24\,898{,}675$$

Then:

$$k = \frac{0{,}0001}{24\,898{,}675} = 4 \cdot 10^{-9}\ [m \cdot s^{-1}]$$

Volume flow rate is:

$$Q = 4 \cdot 10^{-9} \cdot 400 \cdot 24\,898{,}675$$
$$Q = 0{,}04\ [m^3 \cdot s^{-1}]$$

The result of volume flow rate calculated from the Darcy´s law should be in this case 0,04 $m^3 \cdot s^{-1}$.
If we use modified equation for calculation according to Darcy´s law:

$$Q = \frac{S \cdot (p_2 - p_1) \cdot k}{2 \cdot \eta \cdot h}$$

Q flow rate of fluid or gas [m³/s]
k environment permeability [m^2]
S surface [m²], the flowing medium flows through this surface
p_1 inlet pressure
p_1 outlet pressure
h depth
η dynamic viscosity for CO_2 $13{,}9 \cdot 10^{-6}$ [Pa·s]

then:

$$Q = \frac{400 \cdot 24\,898\,675 \cdot 1 \cdot 10^{-13}}{2 \cdot 13{,}9 \cdot 10^{-6} \cdot 1\,000}$$

$$Q = 0{,}036\ [m^3 \cdot s^{-1}]$$

As we can see, the result of volume flow rate is almost equal from the both equation. Now we verify this result with output of modeling and simulation in CFD software Fluent.

9.2. Modeling and simulation

Based on modeling and simulation at Fluent software we can clearly identify: pressure rates in modeled area, mass flow rates or velocities, etc.
Scheme of the modeled area is shown in the Figure 5. We model only in 2D in this case. As was mentioned earlier, we assume depth 1000 meters and pressure at this depth 25 MPa.

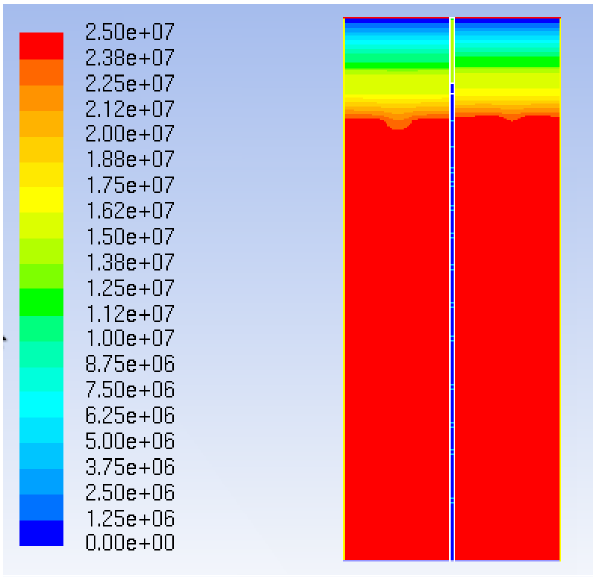

Figure 7. Contours of Static Pressure

Figure 7 shows contours of static pressure at the modeled area.

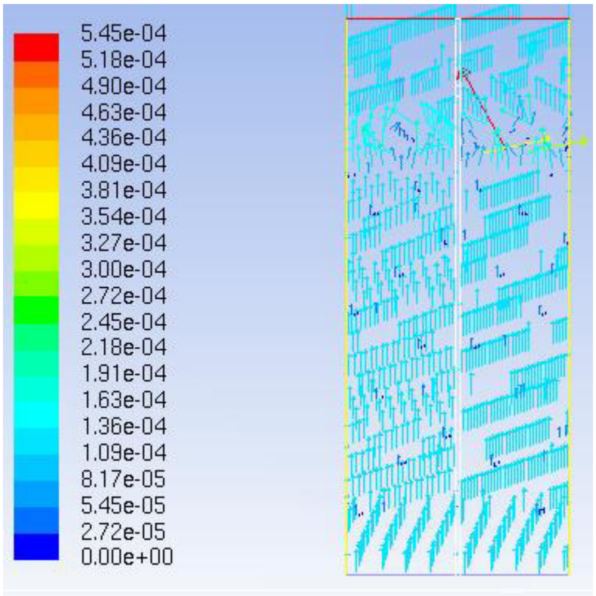

Figure 8. Velocity Vectors

We can see velocity vectors in the Figure 8. There is shown that maximum velocity of flowing gas which is achieved at the area is: $5 \cdot 10^{-4}$ $m \cdot s^{-1}$.
Now, we can focus our intention to numerical outputs of modeling and simulation.

Table 2.Modeling and Simulation Results

Velocity (Aver.)	0,0001 $m \cdot s^{-1}$
Mass Flow Rate	0,08 $kg \cdot s^{-1}$

The mass flow rate at the surface is output of Fluent in this case. The mass flow rate is equal: 0,08 $kg \cdot s^{-1}$.

We can calculate volume flow rate from the common equations:

$$Q_V = v \cdot S$$

$$Q_V = 0{,}0001 \cdot 400 = 0{,}04\ [m^3 \cdot s^{-1}]$$

As we can see, the volume flow rate which was calculated from Darcy´s law ia equal to the volume flow rate obtained from Fluent software.
We can check if the mass flow rate of CO_2 at the surface that was obtained from Fluent will be the same that we calculate based on the following equation and known velocity.

$$Q_m = \rho \cdot S \cdot v$$

$$Q_m = 1{,}8 \cdot 400 \cdot 0{,}0001 = 0{,}072\ [kg \cdot s^{-1}]$$

The results of modeling and simulation are very accurate and we can say that should be respond with real situation. We can assume mass flow rate of CO_2 0,04 $m^3 \cdot s^{-1}$ at area 400 m^2, i tis based on the previous conditions.

10. CONCLUSION

The article responds to the problem of global warming and gasses that are responsible for this. It was mentioned about greenhouse effect and about carbon dioxide at the first part. Then, our focus was concentrated to the possibilities of carbon dioxide capture and storage to the underground. We presented also real examples of CCS.
The main purpose was research whether it would be possible to use the similar principe of CCS at the Czech Republic. The area of former deep coal mine Paskov was choose for this reason and we check possibility of CO_2 storage in this area using by Darcy´s law and numerical computing at Fluent software. In the previous chapter it was proofed that results which were obtained are almost same and we can considered meaningful that.
Generally, working with CFD software mostly involves a multidisciplinary task since a person dealing with the issue of fluid flow modeling must be familiar with hydromechanics, thermodynamics, partially mathematics and chemistry and other disciplines as per the field of application, complexity and type of the issue under examination. In this case, the other disciplines involved geology and mining related knowledge.
It needs to be noted that the paper dealt with modeling situations under simplified conditions. Modeling mining applications where we interface with nature is generally a very complex tasks we can never get a complete set of information on the modeled environment, not only due to the fact that the rock massif is disturbed by the mining activity to such an extent.
The purpose of this paper was summarized the basic knowledge of the capturing and storage of CO_2, introduce our idea of storage at the Czech Republic and check whether the stored CO_2 will leak towards to the surface at the first phase. It was verified that it should flow at the surface around 0,04 $m^3 \cdot s^{-1}$ at the area of 400 m^2at the set conditions.

References

1. Kushnir, Y.: Solar Radiation and the Earth's Energy Balance; EESC 2100 Spring 2007; Available from: <http://eesc.columbia.edu/courses/ees/climate/lectures/radiation/>.
2. Le Treut, H., Somerville, R.: *Historical Overview of Climate Change Science*; Available from: <http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter1.pdf>.
3. Encyklopediemeterologie a klimatologie; Available from: <http://www.meteocentrum.cz/encyklopedie/sklenikovy-efekt.php>.
4. The Greenhouse Effect; Available from: <http://environment.nationalgeographic.com/environment/global-warming/gw-overview-interactive/>.
5. Lát, J.: *Dobývánínízkýchplošeuloženýchslojívesložitýchdůlněgeologickýchpodmínkách*. MŠMT ČSR Praha (1988).
6. Lát, J.: *Výstupyplynů z dolunapovrch v oblastech s ukončenouhornickoučinností*. Uhlírudygeologickýprůzkum, 7/2000, Praha, 2000, s. 10 – 15, ISSN 1210 - 7697.
7. Lát, J., Truneček, T.: *Výstupmetanu z Hrušovskéhodolu v OKR*. ZÁCHRANÁŘ, ročník XXXVII, Ostrava-Radvanice, RBZS Ostrava, listopad 2000, s. 10-11.
8. Skleníkovéplyny; Available from: http://ec.europa.eu/clima/sites/campaign/pdf/gases_cs.pdf.
9. Statoil; CO_2 capture and storage; Available from: <http://www.statoil.com/en/technologyinnovation/newenergy/co2management/pages/carboncapture.aspx>.

10. Statoil; Sleipner West; Available from: <http://www.statoil.com/en/TechnologyInnovation/NewEnergy/Co2Management/Pages/SleipnerVest.aspx> and<http://www.statoil.com/en/OurOperations/ExplorationProd/ncs/sleipner/Pages/SleipnerVest.aspx>.
11. leipner—A Carbon Dioxide Capture-and-Storage Project; Available from: <http://www.planetseed.com/node/15252>.
12. Carbon Capture and Storage; Available from: <http://climateanswers.info/2009/06/carbon-capture-and-storage/>.
13. Staša, P., Kebo, V., Fuchsíková, P., Kubáč, L.: *Modelling potential action for building protection against flow of methane from the underground using the Fluent software*; Proceedings of the 13th International Carpathian Control Conference (ICCC), High Tatras, Podbanské, Slovak Republic, 2012; indexed in the IEEE Xploredatabaze; submitted to A&I Partners (ISI Web of Knowledge, SCOPUS); IEEE Catalog number: CFP1242L-CDR; ISBN: 978-1-4577-1866-3.
14. Staša, P., Kebo, V.: *Modeling of ventilation and methane behavior at coalface area of underground coal mines using by CFD program* (Reviewed Paper); Proceeding of International Symposium on Earth Science and Technology 2010, Fukuoka, Japan; CINEST 10-48; pages: 253-258; ISBN: 978-4-9902356-0-4.
15. Staša, P., Kebo, V., Strakoš, V.: *Modeling the flow of methane in area with end-mining activities in the city of Ostrava using CFD program Fluent* (Reviewed Paper); Proceeding of International Symposium on Earth Science and Technology 2011, Fukuoka, Japan; CINEST 11-B6; pages: 171-176; ISBN: 978-4-9902356-1-1.
16. Chovancová, K.: *Snižováníemisíoxiduuhličitého a jehovyužití k ukládání do podzemí*; Bachelor thesis, VSB-Technical University of Ostrava, Faculty of Mining and Geology; Ostrava 2012, 45 pages.
17. Capture and Storage of CO_2; IEA Greenhouse Gas R&D Programme; Available from: <http://www.ieaghg.org/docs/general_publications/2.pdf>.
18. Shakhashiri: *Carbon Dioxide*; Available from: <http://scifun.chem.wisc.edu/chemweek/pdf/carbondioxide.pdf>.
19. STAŠA, P., KEBO, V., STRAKOŠ, V., FUCHSÍKOVÁ, P.: *Modelling of methane flow in porous environment with one active degassing borehole located in the cavern using the CFD programme Fluent*; Proceedings of the 12th International Multidisciplinary Scientific GeoConference SGEM 2012, Albena, Bulgaria; indexed by ISI Web of Knowledge, Web of Science and also CrossRef DOI received. Paper will be submitted to SCOPUS, ProQuest and GeoRef; ISSN: 1314-2704.
20. STAŠA, P., KEBO, V., STRAKOŠ, V., FUCHSÍKOVÁ, P.: *The efficiency comparison of degassing porous environment by two different options of degassing using modelling and simulation*; Proceedings of the 12th International Multidisciplinary Scientific GeoConference SGEM 2012, Albena, Bulgaria; indexed by ISI Web of Knowledge, Web of Science and also CrossRef DOI received. Paper will be submitted to SCOPUS, ProQuest and GeoRef; ISSN: 1314-2704